REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 074-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
November 2001

3. REPORT TYPE AND DATES COVERED
Interim, Jun 00 – Nov 01

4. TITLE AND SUBTITLE
An Integer Linear Program to Recommend Stationing of Army Forces

5. FUNDING NUMBER
N/A

6. AUTHOR(S)
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Center for Army Analysis
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10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Co-sponsor
Operations Research Department, Naval Postgraduate School, Monterey, CA 93940

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release, distribution unlimited.

12b. DISTRIBUTION CODE
A

13. ABSTRACT *(Maximum 200 Words)*
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14. SUBJECT TERMS
Base Realignment and Closure (BRAC), Efficient Facilities Initiative (EFI), integer linear programming, Army stationing, facility location problem

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500
Standard Form 298

20020904 061

An Integer Linear Program to Recommend Stationing of Army Forces

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69th MORS Symposium
Working Group 22 – Analytical support to Training
12-14 June 2001
(November 2001)

In an October 2001 letter to the Chairman and ranking members of the Senate and House Armed Services Committees, eight former Defense Secretaries urged Congress to approve another round of military base closings, saying it is necessary for the US fight against terrorism. The current Defense Secretary, Donald Rumsfeld, has similarly urged Congress for authority to undertake another round with many of his justifications spelled out in the 2001 Quadrennial Defense Review (QDR). This paper presents an integer linear program, OSAF (Optimal Stationing of Army Forces) used by the Army for analyses to support the 2001 QDR. OSAF enables systematic examination of Army stationing alternatives and prescribes an optimal Army stationing for a given force structure, set of installations, available implementation dollars, and stationing restrictions. Each alternative stationing solution satisfies numerous unit requirements and is evaluated with a set of quantitative and qualitative metrics. We find a more efficient stationing of current Army forces can improve the use of Army facilities, ranges, and training land assets, as well as meet unit requirements at reduced cost. We also discuss the impact of some common stationing restrictions and discuss OSAF's planned role in future stationing analyses.

KEYWORDS: Base Realignment and Closure (BRAC), Efficient Facilities Initiative (EFI), integer linear programming, Army stationing, facility location problem

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INTRODUCTION

Recently, eight former Defense Secretaries (Harold Brown, Frank Carlucci, William Cohen, Melvin Laird, Robert McNamara, William Perry, James Schlesinger, and Caspar Weinberger) urged Congress to approve legislation providing for another round of politically unpopular military base closings, saying it is necessary for the US fight against terrorism. In their October 2001 letter to the Chairman and ranking members of the Senate and House Armed Services Committees, the ex-Secretaries write: "While we understand the sensitivity to this effort, our support for another round is unequivocal in light of the terrorist attacks of September 11, 2001" (Washington Post, 2001). The ex-Secretaries echo Defense Secretary Donald Rumsfeld's calls for authority to conduct another round of base realignment and closure (BRAC) with the goal of eliminating unneeded infrastructure and freeing defense dollars for other uses. The 2001 Quadrennial Defense Review (QDR) discusses the need for an additional BRAC round or Efficient Facilities Initiative (EFI) (Department of Defense, 2001).

This paper presents an integer linear program, OSAF (Optimal Stationing of Army Forces) developed for the Army Assistant Chief of Staff for Installation Management (ACSIM) and used by the Army for analyses to support the 2001 QDR in response to its overarching question, "What are the infrastructure requirements to support the Army of the future?" OSAF enables systematic examination of Army stationing alternatives and prescribes an optimal Army stationing for a given force structure, set of installations, available implementation dollars, and stationing restrictions. Each alternative stationing solution satisfies numerous unit requirements and is evaluated with a set of quantitative and qualitative metrics.

In the following sections we provide a summary of OSAF inputs, review some past Army stationing analyses, provide an explanation of the model including assumptions and limitations, highlight data observations, present sample results, and discuss some risks. We conclude with a comment about future stationing analyses.

OSAF INSTALLATIONS AND UNITS

The Deputy Chief of Staff for Operations and Plans (ODCSOPS) categorizes Army installations based on the installation's primary mission. OSAF addresses five different installation types that share similar characteristics in the continental US (CONUS): maneuver, command and control, professional schools, major training areas, and training schools. OSAF includes each installation's available heavy and light maneuver training capacity, ranges, and facilities, and unit requirements for these assets. In this paper, we consider the current force structure consisting of 514 major units on 44 installations and training areas (Figure 1) as well as a number of leased facilities. We also include all National Guard and Reserve Component requirements.

The Department of the Army (DOA) divides its building types and ranges on each installation into 353 facility category groups (FCGs) (DOA, 2000a). However only a handful of these 353 provide the majority of the square footage units require and were significant factors in past BRAC studies (ACSIM, 2001). For results presented in this paper, we model 30 facility FCGs aggregated into the following eight groups: operations/administrative, aviation maintenance, vehicle maintenance, supply & storage, training instruction (active

force), community facilities, and enlisted unaccompanied housing. Additional FCGs can be added if deemed necessary.

the ITC). Additional range types can be added to the model as ARRM data matures and becomes available.

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Maneuver
- Fort Bragg
- Fort Campbell
- Fort Carson/Pinion
- Fort Drum
- Fort Hood
- Fort Lewis/Yakima
- Fort Richardson
- Fort Riley
- Fort Stewart
- Fort Wainwright/Greely
- Schofield barracks

Major Training (Active)
- Fort AP Hill
- Fort Irwin
- Fort Polk

Professional Schools
- Carlisle Barracks
- Fort Leavenworth
- Fort McNair
- West Point

Training Schools
- Fort Benning
- Fort Bliss
- Fort Eustis/Story
- Fort Gordon
- Fort Huachuca
- Fort Jackson
- Fort Knox
- Fort Lee
- Fort Leonard Wood
- Fort Rucker
- Fort Sam Houston
- Fort Sill
- Ordnance School at Aberdeen

Command & Control/ Administrative Support
- Fort Belvoir
- Fort Buchanan
- Fort Hamilton
- Fort McPherson/Gillem
- Fort Meade
- Fort Monroe
- Fort Myer
- Fort Shafter

Figure 1. (U) Installations in OSAF

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The Installation Status Report (ISR) (DOA, 2000c) provides a quality rating (green=good, yellow=fair, or red=poor) for each square foot of each FCG at each installation. With approval from the ASCIM, OSAF combines these groups into green and other. It assumes any unit stationed to a new installation is given green-rated facilities or new construction. If only other-rated facilities are available, an upgrade cost is applied to upgrade existing facilities to green. OSAF does not upgrade the facilities for units that remain on an installation (units that do not move) and assumes that green-rated facilities are the last ones to be evacuated by units leaving an installation.

OSAF uses metrics from the ODSCOPS' Installation Training Capacity/Army Range Requirements Model (ITC/ARRM) that provides maneuver and range requirements (DOA, 1999). It includes the eight most influential range types (highest weights in the ITC).

Range requirements are expressed in range-days and maneuver land requirements expressed in kilometer-square-days (km^2days). OSAF restricts the deviation between the required and available training assets. In so doing, it ensures that moving units do not increase training asset shortfalls. A subset of units can train at installations where they are not assigned.

OSAF COSTS

Consistent with prior stationing analyses, OSAF considers both recurring and one-time costs. Recurring costs are further divided into variable and fixed costs.

Fixed costs are costs that occur regardless of the number of soldiers on an open installation. (If OSAF chooses to inactivate an installation, it avoids paying fixed costs after the installation is closed.) The fixed cost includes fixed base operating costs for Garrison activities and the

minimum community facilities. Cost factors and relationships are from standard ACSIM sources: Unit Relocation Cost Model (URCM) (R&K, 2001) and the ISR.

Every unit stationed generates a variable cost for installation operations; implemented as a cost per soldier or civilian assigned to an installation. OSAF uses a variable cost based on three cost categories: Base Operating Support (BOS), Real Property Maintenance (RPM), and housing operations and allowances.

One-time cost is divided into military construction (MILCON), transportation, and program management. All stationing actions that include the movement of a unit or closure of an installation incur one-time costs in these three major areas. If an installation that receives a new unit does not have the required green-rated facilities or ranges available, then a one-time MILCON cost is assessed for new construction or (if available) an upgrade from other-rated facilities. We constrain OSAF by a maximum one-time cost available for all stationing actions.

All unit movements incur a one-time transportation cost (Forces and Organization Cost Estimating System – FORCES and URCM). The transportation cost includes the movement of civilians, equipment, military families, and the military unit. As in prior stationing analyses, we assume a normal rotation policy for military personnel and their families that decreases the OSAF portion of movement costs associated with a stationing action.

PAST STATIONING ANALYSES

There are four primary differences between OSAF and Army analyses for similar installations in the last BRAC round in 1995 (BRAC95).

1. BRAC95 analyses started with a detailed installation and military value assessment including *estimated weights* for numerous installation characteristics. For example, a command and control installation could get a maximum of 140 points for their operations and administrative facilities out of 450 points in the Mission Requirements and Operational Readiness Category (DOA, 1995). The Army evaluated installations on numerous categories, summed the weighted scores, and ranked installations. These rankings served as the basis for evaluating Army stationing alternatives. In contrast, OSAF does not rank installations. Instead, it examines all alternatives with respect to facility and training requirements, and economics (costs, savings, and Net Present Value (NPV)), constrained by mission related restrictions.

2. BRAC95 stressed the "payback" metric to evaluate an alternative (the period it takes for savings to exceed implementation costs) and used the Cost of Base Realignment Actions (COBRA) Model (R&K, 1994) to complete this analysis. If an alternative did not meet the payback cutoff, it was discarded. Unfortunately, this approach favors short-term gains over some potential long-term savings and may contribute to overlooking beneficial moves that occur simultaneously between different sets of installations. Theoretically, one high cost move could enable several other moves that in the long run (20-year period) could result in considerable savings. In contrast, OSAF simultaneously considers multiple unit movements and NPV. The NPV metric allows for a long-term perspective and follows United States General Accounting Office (GAO) guidance to "use the current discount rate tied to the U.S. Treasury's borrowing rate to calculate the net present

value" (GAO, 1997) for these types of actions.

3. Stove piping or restricting stationing between similar types of installations typified Army BRAC95 analyses. The "Army's process began by categorizing installations according to their current functions; broader alternative uses were not considered" (Hix, 2001). Because such restrictions can limit potential savings, we do not restrict stationing among installation types.

4. BRAC95 exempted 26 installations from closure based on their high ranking. In OSAF, we do not exempt installations based on their ranking.

Integer linear programming efforts have been used to assist the Army with some of their past stationing efforts. The Total Army Basing Study office used Optimally Stationing Units to Bases (OSUB) to suggest stationing alternatives during past BRAC analyses (Dell, et al., 1994). OSUB maximizes the military value of maneuver and training installations using weighted factors from BRAC military value assessments, or OSUB minimizes yearly operating cost, or it uses a combination of the two. OSAF builds on OSUB but in contrast to OSUB, it contains additional installation types, facility information, facility quality from the ISR, additional ranges, the new km^2Days metric for maneuver lands, additional cost categories, and OSAF minimizes the NPV of base operation, closure, and realignment costs.

Loerch et al. (1996) examine possible stationing policies for the Army's European theater. Their model minimizes annual cost subject to constrained resources, implementation costs, unit proximity, and support requirements. Other Army BRAC analyses using integer linear programming include Singleton, (1991), Tarantino, (1992), and Dell, (1998).

SUPPORTING MODELS

The OSAF Integer Linear Program (ILP) recommendations provide a starting point for further analyses with supporting models. Starting with OSAF recommendations, we complete an impact assessment that examines additional details including strategic implications, political concerns, environmental issues, impacts on deployment, and other issues suggested by the recommended stationing.

ACSIM and ODCSOPS have numerous models to assist them with stationing analyses; among them is URCM. URCM is an updated version of the COBRA model that was used to evaluate cost and savings for all Department of Defense BRAC actions in 1991, 1993, and 1995.

URCM is a spreadsheet-based model. The URCM user must establish the stationing alternative or scenario that includes the units to move and installations to close. Using this scenario input, URCM calculates the associated costs and savings for the moves. Without the aid of a model such as OSAF, scenario development for URCM can take several days to fulfill and then additional time to examine the results. While URCM includes all facility requirements, it does not include training information.

OSAF ASSUMPTIONS

Key OSAF assumptions are consistent with past Army stationing analyses or are suggested by critiques of those analyses conducted by the GAO and other agencies.

Facility Aggregation

We can aggregate similar FCGs with minimal loss of solution fidelity. We base this assumption on past stationing analyses that identify key FCGs impacting stationing decisions.

Training Metrics

For each installation, the single metric, days, adequately portrays its range availability and km^2Days adequately portrays its heavy and light maneuver land availability. Treating km^2Days and range days as a linear commodity may provide an optimistic portrayal of maneuver land availability. By altering days available the impact can be assessed.

Local Community

The local community surrounding an installation can meet housing and utility requirements not met by an installation's assets. In remote areas, this assumption may be overly ambitious so we examine possible impacts for OSAF recommendations using other sources, for example, MILCON and distant communities.

Enclaves

When OSAF recommends moving all Active Component units from an installation (inactivating the installation), Army Reserve and National Guard units remain behind in an enclave along with non-Department of Defense (DOD) tenants. An enclave ensures installation availability, potentially limits environmental cleanup impacts, and provides Reserve and National Guard additional stationing assets.

Environmental Restoration

The DOD or the Army will pay environmental remediation costs for the majority of Army bases over the next 50 years. We assume these costs for any closing installation are accelerated to accommodate any closure. We report a potential opportunity cost associated with the acceleration, but consistent with past BRAC analyses, OSAF does not consider this cost.

LIMITATIONS

We do not currently station National Guard and Reserve forces. The National Guard Bureau and ACSIM have a Memorandum of Agreement to integrate Army National Guard data into the standard Army system ACSIM uses for stationing analysis (ACSIM, 2000). Once this integration is complete, their inclusion should be easier to facilitate.

OSAF does not currently consider joint service installations, but a stationing alternative that considers all Service installations especially in high density geographical areas would be beneficial to the Army. After data and decision rules are available for inter-Service use as requested by GAO (1997), we highly recommend other Service installations be added.

When Army units are combined on the same installation, potential efficiencies are gained owing to the possible sharing of resources (*e.g.*, less staff, fewer redundancies). OSAF does not currently include these potential savings due to the lack of any Army standard describing the efficiencies.

QUESTIONS FOR OSAF TO ADDRESS

OSAF can assist the Army in answering numerous stationing related questions. What are the ***infrastructure requirements*** needed to support alternative force structures? Real Property Planning and Analysis System (RPLANS) (DOA, 2000b)

provides facility requirements and ARRM provides training range and land requirements for each unit. Given the force structure, OSAF can then determine infrastructure requirements for a set of facilities, range types, and maneuver lands.

Which Active Component ***units should be stationed where*** based on training requirements, facility requirements, and cost? OSAF considers unit training and facility requirements and matches them with installations that can best satisfy Army-wide requirements.

What facility types and/or ***cost drivers*** significantly impact stationing solutions? Post-analysis of BRAC95 actions provides numerous insights on expected cost drivers. OSAF determines what cost elements are driving alternatives and what elements are inconsequential (not necessarily an irrelevant or trivial expense, but does not drive recommendations).

What is the ***one-time cost*** to improve infrastructure to an ISR level green-rated for various force structures?

Does "***stove piping***" by installation type or other stationing restriction limit potentially favorable alternatives? Stove piping limits potential stationing actions by not allowing moves across installation types. OSAF (at the request of ACSIM) measures the impact of this type of stove piping.

"***What if***" analysis provides the impact on facilities, training, and costs for different stationing actions. This what-if capability is a key analytical strength. From any stationing alternative we can examine single moves, installations closing, forced actions, stationing restrictions, and cost limitations.

What is the ***capacity utilization*** of the infrastructure and training assets for alternative stationing? For example, an installation with 100 square feet of an FCG when all units on the installation require a total of 90 square feet of the same FCG has a capacity utilization factor for that FCG of 90 percent. Ideally the Army would have high capacity utilization factors for facilities, ranges, and training lands.

Cost Analysis provides an idea of the economies that the Army might achieve through a stationing exercise. Costs and resulting savings are estimates based on the best information available. History has shown that even with the complexity of moving units and inactivating installations, BRAC cost estimates are adequate for planning purposes. (GAO, 1999)

THE OSAF ILP OVERVIEW

The OSAF ILP, (see Appendix for a formulation) is implemented in the General Algebraic Modeling System (GAMS) (GAMS, 1998) and solved using the CPLEX 7.0 solver (GAMS, 2000). A typical OSAF run, 22,000 variables of which 4,000 are binary and 8000 constraints, solves in approximately 2 minutes on a personal computer.

OSAF data inputs include units, installations, cost factors, and sponsor guidance. The overall driver for any stationing analysis is an Army Stationing Strategy. The Strategy provides conceptual guidance and in effect limits the stationing rules that need to be applied in the model.

OSAF has an option for using either of two objective functions. The first objective function minimizes the NPV for all one-time and recurring costs over a given time period. The second (alternative) objective function minimizes annual recurring costs and a weighted (penalty) contribution for one-time cost. The NPV approach is the preferred objective because it has a long-term perspective and provides a recognized methodology for weighting costs (time-value of money).

Because the yearly cost of maintaining facilities and ranges impacts the Army's ability to maintain facilities for training, OSAF includes the yearly recurring cost in its objective functions. Because there could be a large one-time cost to move units to different installations in order to achieve the minimum NPV or yearly recurring cost, OSAF can limit the maximum one-time cost. Thus, we view a force-structure stationing as a tradeoff amongst shortfalls in facility and training assets, yearly recurring cost, and one-time stationing costs. OSAF provides alternatives for a given force structure by varying the allowed facility or range shortfall and one-time cost.

We vary one-time funding available or available implementation funds to develop alternatives. For example, if we run OSAF, with zero available implementation funds, we derive the status quo alternative. As we increase available implementation funding, it moves an increasing number of units and deactivates more installations. The model continues to consolidate until it cannot find a realignment that improves the 20-year NPV. At each new level of implementation funding OSAF generates the optimal solution and represents an alternative for Army stationing.

CONSTRAINTS

All stationing must adhere to the Army Stationing Strategy and force structure. The Army Stationing Strategy provides general operational requirements and stationing guidance for each installation category. The Strategy limits or directs certain possibilities, and the force structure drives the unit and thus land, range, and facility requirements.

One set of constraints forces the model to provide all of a unit's required facilities to be in a certain condition. For example, if a unit moves from installation A to B, then these constraints ensure installation B has the required facilities for the unit in green-rated condition.

The second set of constraints is for ranges and training lands. The model ensures shortages in km^2Days and range-days do not increase due to stationing of units. For example, if a unit requires 100 days on a zero range, then OSAF ensures the range-days are available on the installation, or it accounts for the needed MILCON to obtain the range-days on the installation to make up for shortages.

The third set of constraints is stationing restrictions or special stationing considerations (e.g., do not move the Fort Leavenworth prison complex). These rules are developing over time as we use OSAF and discuss results with the ODCSOPS and the ACSIM. OSAF can determine the cost of each stationing restriction and thus indicate how much the Army should be willing to pay to complete tasks that would eliminate the need for a restriction.

The last set of constraints limits the total funds available for one-time or implementation costs. For example, the total implementation cost could be one billion dollars. Or, we can limit implementation costs at the category level: \$200M for MILCON and \$2M for program management.

OSAF can accommodate strategic guidance and force structure changes through its data inputs and stationing restrictions. An example is the introduction of Interim Brigade Combat Teams (IBCTs) in the force. OSAF can include IBCTs by adding them as units with requirements and can then either force them on an installation or examine different stationing alternatives. A second example of a structure change would be the forced withdrawal from OCONUS installations. OSAF could

include such units and examine potential stationing.

DATA OBSERVATIONS

While gathering data for a model such as OSAF, the collection often provides many insights.

GAO (1997) concludes that the "DOD continues to maintain large amounts of excess infrastructure, especially in its support functions, such as maintenance depots, research and development laboratories, and test and evaluation centers." We have found that excess infrastructure does exist in the OSAF installation types, but not to the same extent with the current force structure as GAO finds in the support installations.

As the Army loses force structure it also decreases facility requirements. The ACSIM asked what is the relationship between force structure and facility requirements. If the Army loses 10 percent of its force, will it lose 10 percent of its facility requirements?

If we look at the required square footage per person for the 16 largest unit groups in OSAF (Figure 2), we see the SF requirement ranges from ~550 to ~1,400 SF per person. The per-person disparities tell us that if the Army loses 10 percent of the force, it does not necessarily require 10 percent fewer facilities. Looking at the table on the right of Figure 2, we see 12 of the 16 largest Army units have a greater percentage of Army personnel than their corresponding facility requirements and four have a lower percentage of personnel than of facility requirements.

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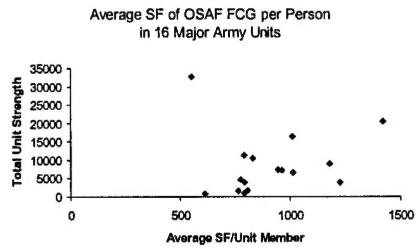

	SF	Personnel
1	0.4%	0.7%
2	0.6%	0.8%
3	0.9%	1.2%
4	1.0%	1.3%
5	3.7%	3.1%
6	2.4%	3.2%
7	2.8%	3.7%
8	5.2%	5.4%
9	5.3%	5.7%
10	5.4%	6.0%
11	8.1%	7.2%
12	6.8%	8.5%
13	6.9%	9.1%
14	12.7%	13.1%
15	15.5%	14.5%
16	22.3%	16.4%

%SF of total requirement (OSAF FCGs) and % personnel of all personnel of 16 major units.

Gray~ Personnel > SF req.

Figure 2. (U) Unit facility requirements

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In addition to improving cost and facility utilization, another primary reason to restation is to mitigate the imbalance of training lands throughout the Army. When we look at the overall Army, it has enough training lands (gross of all lands), but with the current stationing plan, numerous installations are short – cannot meet their unit requirements. By restationing, we can *possibly* improve the balance between available lands and unit requirements throughout the Army, but data indicate the majority of training lands are placed only in a few locations. Thus, a full utilization of these lands would require extensive relocation, implementation costs, MILCON, and would have serious impacts on local communities. Additionally, the strategic implications could be significant. For example Alaska has over 50 percent of the light and over 30 percent of the Army's heavy maneuver lands (CAA, 2001), but because it is also one of the highest cost areas and has environmental considerations, it is not the ideal location for the preponderance of US forces. This being the case, the Army can take advantage of stationing to resolve some maneuver land

shortages, but it will still be short, even after restationing, at some installations.

STATIONING METRICS

The OSAF ILP prescribes stationing solutions that we measure using the following six metrics.

NPV and Cost

For both objective functions (NPV and yearly costs), we measure a combination of fixed, variable, and implementation costs (smaller is better). Each alternative has an implementation or one-time cost for transportation, MILCON, and program management. The higher the allowed implementation cost, the greater the possibilities for stationing actions.

Complexity

Each alternative has a number of units that are moved. The more units that move, the more complex it is assumed to be for the Army to implement.

Payback

Past stationing analyses concentrated on the payback period when evaluating a solution. OSAF can measure and does calculate payback, but we do not recommend it as a factor to distinguish between alternatives. We agree with Hix (2001) "Options that require substantial one-time construction or other transition costs should not be dismissed out of hand before considering the net present value of the long term stream of costs and savings."

Utilization Factors

Stationing should improve the overall Army utilization factors for facilities, ranges, and lands, but this is a secondary concern. The primary concern is the availability of resources to meet requirements at least cost. If an optimal alternative has poor utilization, the Army could always move additional units to improve the utilization at an increased cost (according to model runs) for the current force structure. A low utilization rate could justify the mothballing of facilities.

Impact Assessment

Because the above metrics cannot capture all considerations of such a complex process as the stationing of Army forces, we examine all alternatives further with an impact assessment, a more subjective, post-processing step. This assessment includes a panel's review for unique requirements not captured in OSAF including four key areas: strategic implications, political constraints, environmental issues, and impacts on deployment.

- Strategic implications represent the Army's ability to fulfill its mission mainly from a geographical perspective. For example, the Army cannot put all forces on one coastline or a preponderance of forces in Alaska regardless of costs owing to other strategic concerns (e.g., homeland defense).

- Possible political "constraints" are examined in terms of their cost and possible impacts on alternatives. Each installation has its own set of political considerations; OSAF does not attempt to model these constraints. As Carter and Perry point out, "Every member of Congress wants to reduce unnecessary defense spending, but no member wants to close a base or a government depot in their district" (Carter and Perry, 1999). If a political constraint is added to the model, OSAF can determine the cost of imposing the constraint. From an Army perspective, this ability helps leadership determine what political constraints impact stationing.

• Environmental assessment includes remediation costs and an examination of possible concerns from the Environmental Relocation Cost Model (ERCM) assessment. (ERCM is a component of the ITC that assesses environmental and demographic issues.) (DOA, 2001b) For example, encroachment, water quality, and cultural resources are environmental areas that this part of the impact assessment would address.

• For unit deployment requirements, we determine if the stationing of a large maneuver force will stress existing deployment infrastructure (e.g., railheads and airfields) at the unit's new location.

SAMPLE RESULTS

An Army-wide system of moves has the potential to save the Army billions of dollars (NPV). Savings are not realized for numerous years due to the implementation costs involved. Even though stationing actions do not provide short-term budget assistance, they should still be considered and possibly executed. Otherwise, 10 years from now the Army will face the same installation situation, cost issues, and the same dilemma of short- versus long-term perspective.

Figure 3 represents 10 different solutions (example results) or alternative stationing actions at different levels of implementation cost using the minimize yearly cost objective function. Each point in the graph is the 20-year NPV and includes implementation costs. In the top graph, the Y-axis is in \$10Bs, the status quo is the horizontal line ~\$120B, and the X-axis represents the 10 alternatives. The bottom graph illustrates the level of implementation funding (\$B). Alternative #1 has zero implementation funds representing the status quo alternative. Alternative #10 has unlimited implementation funds.

From Figure 3, we see alternative #3 has a 20-year savings in NPV of approximately \$2.80B, #4 ~\$7.20B, #5 ~ \$7.63B, and #6 ~ \$7.50B. Implementation costs differ between alternatives from \$850M to over \$8B dollars.

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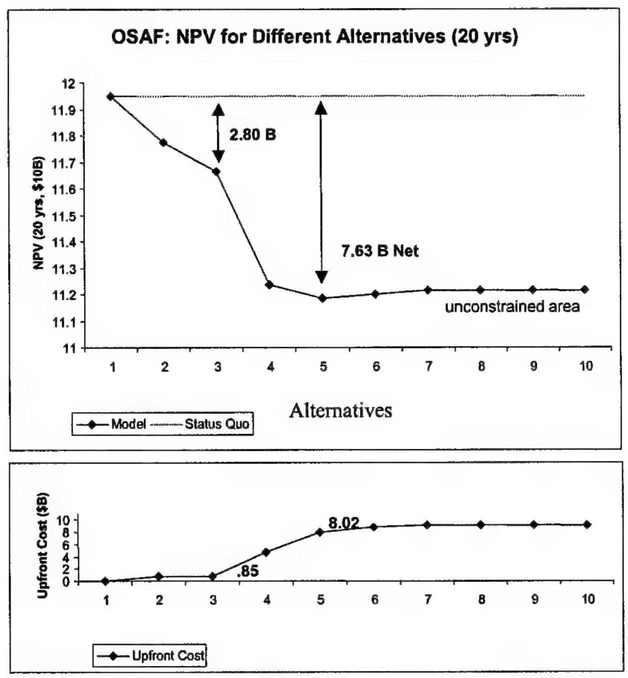

Figure 3. (U) Evaluating results

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Alternatives #5 has the best NPV, but #4 has a small degrade in NPV with about half the implementation cost. Alternative #6 has a higher NPV than #5 and uses a higher level of implementation dollars; however, the additional monies are used on moves that improve recurring costs but not NPV. The figure illustrates how we can examine alternatives at different implementation funding levels and generate both the recurring yearly costs and NPV.

When examining alternatives, the Army should consider all metrics. Figure 4 provides a matrix for the example alternatives in Figure 3 and how they compare within the set of metrics. The black denotes the worst case for the corresponding metric and the white denotes the best case. For example, the "current" stationing is black for NPV because it has the highest NPV of all alternatives while alternative #6 is white for recurring costs because it has the lowest recurring cost of all alternatives.

The benefit of multiple metrics is evident in the matrix; metrics highlight the pros and cons of each alternative. If the Army's goal is to maximize utilization, then a cost is incurred in the NPV, implementation costs, and complexity metrics. If the Army wants to minimize NPV, then a cost is incurred with implementation costs and complexity (number of moves).

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	Alternatives				
Metrics	Current	3	4	5	6
NPV (lower is better)					
Implementation Cost	N/A				
Complexity	N/A				
Capacity Utilization					
Min. recurring costs					
Color Code for alternatives:	Worst				Best

Impact Assessment	Examine each area for negative impacts
Other Issues	Examine alternative characteristics

Figure 4. (U) Differences in alternatives

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Parameters

Figure 5 shows that of the eight primary parameters in the model, the BOS costs have the most influence on alternatives. (For a complete description of all OSAF parameters, equations, and relationships see Connors et al (2001), Appendix G.) The variable BOS influences moving of individual units, while the fixed BOS is an incentive to close an installation. OSAF tends to prefer a small number of large multipurpose installations apparently for their available resources and cost efficiencies.

The maneuver land requirement is also a major driver due to limited availability and the large requirements for some units. OSAF generally avoids deactivating installations with maneuver land. But allowing a light maneuver requirement to use heavy training lands allows a maneuver installation to close. By varying maneuver land availability, we can increase opportunities to station and support the development of real estate acquisition strategies.

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Parameter	Influence on Alternatives	Comments
Base Operating Support	**Major**	Fixed/Variable Cost
Maneuver Land	**Major**	Adjustable limits
MILCON	**Major**	One Time Cost
Housing	Moderate	Variable Cost
Real Property Maintenance	Minor	Variable Cost
Ranges	Minor	Adjustable limits
Program Costs	Minor	One Time Cost
Moving	Minor	One Time Cost

Figure 5. (U) Parameter insights

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OSAF often targets command and control/administrative installations for deactivation. Command and control installations tend to be administrative installations with very little, if any, maneuver land. Because of this, the model sees little motivation to keep the installation open when cost savings can be obtained by moving the units. This targeting ignores mission related or geographical reasons to keep the installation open.

The most influential implementation cost is MILCON.

Ranges are a minor influence on moving. OSAF allows shortages to exist (they exist in status quo case) up to a certain level. Beyond this level, it forces a range purchase. We find that the maneuver land requirements are binding, while the range requirements are not.

Buildable acres is an additional parameter that influences alternatives. We exclude installation with minimal buildable acres from possible *new* MILCON.

WHAT IFS

We examine the results of many changes to OSAF input. For example, take a stationing alternative and from the installations that are closed – force one open. Or, from the installations that are open – force one closed. When we change an installation's disposition, then moving is impacted, and OSAF tells us the cost of the change.

OSAF ensures that the Army maneuver land shortfall does not increase. We can increase or decrease the allowable shortage by installation or for the Army by changing an model parameter. In all cases, a relaxed maneuver land constraint allows additional moving and decreases costs.

The clear division between installation types may be appealing; however, stove piping is the most constraining of policies and should be avoided if possible. Stove piping significantly impacts stationing opportunities (decreases potential savings by over 30 percent).

CAVEATS

Risks exist in any stationing alternative and in the stationing process. The following discusses some elements of stationing that we need to be aware of when examining alternatives.

a. Costs. Historically, the costs for moving (in past BRAC actions) have been hard to estimate and confirm (Numerous examples, e.g., GAO, 1997).

b. Utilities. URCM estimates for infrastructure do not include utility upgrades. There will be a cost incurred for the utility infrastructure required to support new MILCON.

c. Economic assistance. OSAF does not consider the cost of assistance to local communities to overcome realignment impacts. Although these costs may be substantial (GAO, 1996) they are also difficult to estimate in advance of any announced action.

d. Environmental costs. One of the largest costs DOD can face on an installation is the environmental remediation cost. GAO (1997) states that "we have concurred with DOD not considering these costs in developing its cost and savings estimates as a basis for base closure recommendations. At the same time, we agree with DOD's position that environmental restoration costs are a liability to it regardless of its base closure decisions; and we note, these costs are substantial."

e. Training.

- **Estimates.** The current estimates for Army training lands are only estimates and subject to change. We should be reluctant to divest an installation with significant training lands to hedge against shortfalls; future Army systems may require additional training lands.

- **Costs.** A possible training objective would be to move units to installations with lower training costs. Training costs are a function of the installation, command environment, OPTEMPO, environmental factors, local policies, distances to training areas, and other factors not considered in OSAF. A consistent or standardized means to measure training costs across Army units would enable their inclusion.

f. Environmental issues other than cost. Unfortunately, there are many environmental factors that can impact a stationing decision. For example, encroachment (due to growth in the installation's local community) can complicate new construction. Other environmental concerns, such as noise need to be considered with each alternative. Because these impacts are not easily defined, an inherent risk is incurred with moving units.

SUMMARY AND FUTURE USE

In summary, OSAF addresses a very complex problem – an Army stationing analysis. The model considers all guidance and determines an optimal stationing plan for a given set of inputs and stationing restrictions. OSAF establishes a starting recommendation quickly and enables rapid exploration of many what ifs. It integrates (but does not replace) aspects of many supporting higher fidelity Army stationing models.

ACSIM, the study sponsor, has accepted OSAF and feels it meets their requirements for stationing analysis. ODCSOPS and ACSIM have used OSAF to examine two realignments and are preparing to use the model during the upcoming Army Stationing for Transformation Study in 2002 and in any future base realignment and closure action.

APPENDIX: OSAF ILP Formulation

Formulation

Indices:

c	facility condition
f	facility category
i	installation
k	maneuver land measured in km^2days
r	range type measured in days
t	installation type
u	unit
y	unit types

Sets:

CA_u	set of installations where unit u can be assigned
IS_i	initial stationing of units at installation i
N	set of ranges r requiring construction to satisfy any shortage
S	set of installations that share training assets
UA_i	set of units that can be assigned to installation i
FIX	set of installations that are "fixed" open
UT_y	set of units of type y

Data: (all \$ are fiscal year 2001 thousands of dollars and all SF are thousands of square feet)

Cost data (units)

$Fcost_i$	fixed cost of keeping installation i open (\$)
$ManCostC_i$	program management cost to close installation i (\$)
$ManCostM_u$	program management cost to move unit u (\$)
$maxMILCON$	maximum one time cost for military construction (\$)
$maxMOVE$	maximum one time cost for transportation costs (\$)
$maxMAN$	maximum management cost (\$)
$maxCOST$	maximum total cost (\$)
$Mcost_{fi}$	military construction (MILCON) cost for facility type f at installation i (\$/SF)
$Rcost_{ir}$	cost for a new range r at installation i (\$/range)
$UPcost_{fi}$	cost to upgrade facilities type f at installation i (\$/SF)
$Vcost_{iu}$	variable cost if unit u is assigned to installation i (\$)
$CostSustain_{fi}$	cost to sustain existing facilities type f at i (\$/SF)
$CostNew_{fi}$	cost to sustain new facilities type f at i (\$/SF)
$TRcost_{iu}$	transportation cost for moving unit u to installation i (\$)

Range data

$RANm_r$	maximum range days on a new range r
$RANkcap_{ik}$	range capacity of type k at installation i (KM^2Day)
$RANkreq_{ku}$	range required of type k for unit u (KM^2Day)
$RANkshort_k$	existing range shortage for range type k (KM^2Day)
$RANrcap_{ir}$	range capacity of type r at installation i (day)
$RANrreq_{ru}$	range required of type r for unit u (day)
$RANrshort_r$	existing range shortage for range type r (day)
$RANover_i allowRNG_{ir}$	the amount of range shortage allowed for r at installation ii (day)
$allowRNG\_S_r$	the starting range r shortage allowed for set S (day)

$allowKM2_{ik}$	the starting KM^2Days overage allowed for maneuver land k at installation i (KM^2Day)
$allowKM2\_S_k$	the starting KM^2Days overage allowed for maneuver land k and set S (KM^2Day)
$moreRNGshort_r$	multiplicative range r shortage for all installations (day/day)
$moreKM2short_k$	multiplicative KM^2Days shortage for all installations (KM^2day/KM^2Day)
$ADDKM2\_S_k$	shortage allowed for maneuver land k and set S (KM^2 Day)
$ADDRNG\_S_r$	shortage allowed for range r and set S (day)
$ADDKM2_{ik}$	shortage allowed for maneuver land k at installation i (KM^2 Day)
$ADDKM2_{ir}$	additive shortage allowed for range r at installation i (day)
mRNGshort	the minimum range shortage before a range purchase (days)

Facility data

$FACcap_{cfi}$	facility capacity type f at installation i condition c (SF)
$FACreq_{fu}$	facility required of type f for unit u (SF)
$GREEN_{fi}$	green facility type f at installation i not used by currently stationed units (SF)
$OTHER_{fi}$	other facility type f at installation i not used by currently stationed units (SF)

Adjusted Present Value (APV) factor data

APVBOSss	APV for BOS costs for steady state stationing (years 7-20)
APVBOSsq	APV for BOS costs for status quo stationing (years 1-6)
APVBOS	APV for BOS (years 1-20)
APVMILCON	APV for MILCON (years 1-20)
APVMAINTss	APV for maintenance for steady state stationing (years 7-20)
APVMAINT	APV for maintenance (years 1-20)
APVManage	APV for management (years 1-20)

Penalty data

Penalty	weight of one time costs in objective function
overRAN	percent allowed for increase in overall range shortage
overKM2	percent allowed for increase in overall training lands
overR	percent allowed for increase in range shortage at a single installation
overK	percent allowed for increase in land shortage at a single installation

Nonnegative Variables:

$usehvy_i$	percent of heavy maneuver land in use on installation i
$milcon_{fi}$	military construction of facility *f* at installation *i* (SF)
$upgrad_{fi}$	conversion of facility *f* SF in other condition to green condition at installation *i* (SF)
$range_{ir}$	shortage of range *r* at installation *i*
$agreen_{fi}$	green conditioned facilities made available by moves from facility type *f* at installation *I*
$erran_{ir}$	deviation for range type *r* at installation *i* (day)
$ekran_{ik}$	deviation for range type *k* at installation *i* (KM^2 Days)

Binary Variables:

$station_{iu}$	1 if unit *u* is assigned to installation *i* and 0 otherwise
$close_i$	1 if installation *i* is closed and 0 if open

Objective:

(1) Minimize yearly costs and weighted implementation costs:

$$\sum_{i,u\in UA_i} Vcost_{iu} station_{iu} + \sum_i Fcost_i (1 - close_i)$$
$$+ Penalty \Big(\sum_{fi} Mcost_{fi}\ milcon_{fi}$$
$$+ \sum_{ir\in N} Rcost_{ir}\ range_{ir}$$
$$+ \sum_{fi} UPcost_{fi}\ upgrad_{fi}$$
$$+ \sum_{i,u\in UA_i \text{ and } u\notin IS_i} \big(TRcost_{iu} + Man\cos tM_u \big)\, station_{iu}$$
$$+ \sum_i ManCostC_i\ close_i$$
$$+ \sum_{cif} CostSustain_{if}\ FACcap_{cif}\ (1 - close_i) \Big) \tag{0.1}$$

(2) Minimize Net Present Value

$$APVBOSss\left(\sum_{i,u\in UA_i} Vcost_{iu} station_{iu}\right)+$$
$$APVBOSsq\left(\sum_{i,u\in IS_i} Vcost_{iu} station_{iu}+\sum_i Fcost_i\, close_i\right)$$
$$+APVBOS\left(\sum_i Fcost_i\,(1-close_i)\right)$$
$$+APVMILCON\left(\begin{array}{l}\sum_{fi} Mcost_{fi}\; milcon_{fi}\\ +\sum_{fi} UPcost_{fi}\; upgrad_{fi}\\ +\sum_{ir\in N} Rcost_{ir}\; range_{ir}\end{array}\right)$$
$$+APVMAINTss\left(\sum_{fi}\left(\begin{array}{l}CostNew_{fi} milcon_{fi}\\ +\left(\begin{array}{l}CostNew_{fi}\\ -CostSustain_{fi}\end{array}\right)upgrad_{fi}\end{array}\right)\right)$$
$$+APVMAINT\sum_{fic} CostSustain_{fi} FACcap_{cfi}(1-close_i)$$
$$+APVMOVE\sum_{i,u\in UA_i \text{ and } u\notin IS_i} TRcost_{iu} station_{iu}$$
$$+APVManage\left(\begin{array}{l}\sum_i ManCostC_i\; close_i\\ +\sum_u ManCostM_u\, station_{iu}\end{array}\right)$$

Constraint Sets:

$$\sum_{u\in UA_i} FACreq_{fu} station_{iu} \le \sum_c FACcap_{cfi} + milcon_{fi} \quad \forall f,i \tag{2.1}$$

$$\sum_{u\in UA_i \text{ and } u\notin IS_i} FACreq_{fu} station_{iu} \le agreen_{fi} + GREEN_{fi} + milcon_{fi} + upgrad_{fi} \quad \forall f,i \tag{2.2}$$

Constraint Set #1

$$agreen_{fi} + upgrad_{fi} \le OTHER_{fi} + \sum_{u\in IS_i}\ \sum_{i'\neq i \text{ and } i'\in CA_u} FACreq_{uf} station_{i'u} \quad \forall f,i \tag{2.3}$$

$$FACcap_{\text{"other"} fi} exit_{fi} \le upgrad_{fi} \quad \forall f,i \tag{2.4}$$

$$agreen_{fi} \le FACcap_{\text{"green"} fi} exit_{fi} \quad \forall f,i \tag{2.5}$$

Constraint Set #2

$$\sum_{i\in S}\sum_{u\in UA_i} RANrreq_{ru}\, station_{iu} \le \sum_{i\in S}\left(RANrcap_{ir} + erran_{ir}\right) \forall r \tag{2.6}$$

$$\sum_{u\in UA_i} RANrreq_{ru} station_{iu} \le RANrcap_{ir} + erran_{ir} \quad \forall i\notin S, r \tag{2.7}$$

$$\sum_i erran_{ir} \le moreRNGshort_r RANrshort_r \quad \forall r \tag{2.8}$$

$$\sum_i ekran_{ik} \le moreKM2short_k RANkshort_k \quad \forall k \tag{2.9}$$

$$erran_{ir} \le rngshort + RANm_r\; range_{ir} \quad \forall\; ir \in N \tag{2.10}$$

$$\sum_{i\in S} erran_{ir} \le allowRNG\_S_r + ADDRNG\_S_r \quad \forall r \tag{2.11}$$

$$\sum_{i \in S} eKran_{ik} \leq allowKM2\_S_k + ADDKM2\_S_k \quad \forall k \tag{2.12}$$

$$erran_{ir} \leq allowRNG_{ir} + ADDRNG_{ir} \quad \forall i \notin S, r \tag{2.13}$$

$$eKran_{ik} \leq allowKM2_{ik} + ADDKM2_{ik} \quad \forall i \notin S, k \tag{2.14}$$

$$\sum_{u \in UA_i} RANkreq_{u\text{"}HV\_MNVR\text{"}} station_{iu} \leq RANkcap_{i,\text{"}HV\_MNVR\text{"}} usehvy_i + ekran_{i\text{"}HV\_MNVR\text{"}} \quad \forall i \notin S, RANkcap_{i\text{"}HV\_MNVR\text{"}} \neq 0 \tag{2.15}$$

$$\sum_{u \in UA_i} RANkreq_{u\text{"}LT\_MNVR\text{"}} station_{iu} \leq RANkcap_{i,\text{"}HV\_MNVR\text{"}} (1 - usehvy_i) + RANkcap_{i,\text{"}LT\_MNVR\text{"}} + ekran_{i\text{"}LT\_MNVR\text{"}} \quad \forall i \notin S, RANkcap_{i\text{"}LT\_MNVR\text{"}} \neq 0 \tag{2.16}$$

Constraint Set #3

$$\sum_{i \in CA_u} station_{iu} = 1 \quad \forall u \tag{2.17}$$

$$station_{iu} \leq 1 - close_i \quad \forall i \notin FIX, u \in UA_i \tag{2.18}$$

$$\sum_{i' \notin CA_u \text{ and } i' \neq i} station_{iu} \leq close_i \quad \forall i, u \in UT_{DoD} \text{ and } u \in UA_i \tag{2.19}$$

Constraint Set #4

$$\sum_{fi} Mcost_{fi}\, milcon_{fi} + \sum_{ir \in N} Rcost_{ir}\, range_{ir} + \sum_{fi} UPcost_{fi}\, upgrad_{fi} \leq maxMILCON \tag{2.20}$$

$$\sum_{iu \notin IS_i} TRcosts_{iu} station_{iu} \leq maxMOVE \tag{2.21}$$

$$\sum_{iu \notin IS_i} ManCostM_u\, station_{iu} + \sum_i ManCostC_i\, close_i \leq maxMAN \tag{2.22}$$

$$\sum_{fi} Mcost_{fi}\, milcon_{fi} + \sum_{ir \in N} Rcost_{ir}\, range_{ir} + \sum_{fi} UPcost_{fi}\, upgrad_{fi} + \sum_{iu \notin IS_i} (TRcosts_{iu} + ManCostM_u)\, station_{iu} + \sum_i ManCostC_i\, close_i \leq maxCOST \tag{2.23}$$

Objective: The objective function (0.1) minimizes variable and fixed cost and a weighted (penalty) contribution for one-time cost. The second possible objective function, (2), minimizes the net present value for all fixed and recurring costs over a given time period.

Constraint Discussion:

Set #1. Facilities: The first five equations ensure adequate facilities for units; existing units use "Green" then "Other" facilities, and newly assigned units use available Green, Other upgraded to green condition, and new MILCON.

(2.1) Ensure sufficient existing facility square feet at each installation or satisfy the shortage with MILCON.

(2.2) Ensure sufficient green category facility square feet at each installation for units moved to the installation or satisfy the shortage by upgrading or MILCON.

(2.3)-(2.5) Can only upgrade unused other category facility square feet at each installation or the other other/green facilities vacated by a unit stationed at a different installation.

Set #2. Training: These seven equations constrain the stationing alternative's shortage of training lands and ranges.

(2.6) to (2.7) Limit realignment so it does not produce any additional training requirement shortfall outside of allowable limits.

(2.8) to (2.9) The allowable shortfall Army wide includes has to be less than the range shortfall prior to any realignment plus a possible percentage over the original shortage.

(2.10) New ranges must be built to satisfy any shortfall for a subset of range types; however, a new range does not have to be built until a minimum shortage is attained.

(2.11) to (2.12) These equations allow an overage for the set S beyond the starting range or KM2day shortfall.

(2.13) to (2.14) The allowable shortfall for an installation has to be less than the range or KM2day shortfall prior to any realignment plus a possible addition over the original shortage.

(2.15) to (2.16) These equations ensure the light maneuver requirement can be met by the heavy maneuver capacity if heavy capacity is available and has not been fully used by heavy requirements.

Set #3. Stationing Requirements

(2.17) Each unit must be stationed on an installation.

(2.18) Units are not stationed on a closed installation.

(2.19) Units of type "DOD" are moved only after all other units on the installation are moved and the installation is closed.

Set #4. One-time Costs

(2.20) to (2.23) respectively limit MILCON, movement, management, and total one-time cost.

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